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S.A. Morton[1], G.D. Waddill[2], M. Spangenberg[3], E.A. Seddon[3], J. Neal[4], T. Shen[4], J.G. Tobin[1]

1. Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94550
2. Department of Physics, University of Missouri-Rolla, Rolla, MO 65409
3. CLRC Daresbury Laboratory, Keckwick Lane, Daresbury, Cheshire, UK
4. Joule Physics Laboratory, University of Salford, Salford, Greater Manchester, UK

Recently there has been considerable interest in the study of spin injection at ferromagnetic semiconductor heterojunctions and ferromagnetic metal – semiconductor contacts[1,2,3,4]. Studies of n-type semiconductors have demonstrated spin-coherent transport over large distances[5] and the persistence of spin coherence over a sizeable time scale[6]. Clearly such investigations have been stimulated by the potential of the development of 'spintronics', electronic devices utilising the information of the electron spin states. To understand and improve the magnetic properties of ultrathin Fe films on GaAs has been the aim of many research groups over recent years. The interest in this system has both technological and fundamental scientific motivations. Technologically, Fe on GaAs may serve to realize spin electronic devices. From a fundamental science point of view, Fe on GaAs serves as a prototype for studies of the interplay between the crystalline structure and morphology of an ultrathin film, its electronic structure and the long range magnetic order it exhibits. Furthermore, it is well known that an oxidised Cs layer on GaAs substantially alters the work-function of the GaAs surface, which plays a very important role in the application of GaAs as a spin polarised electron source.

In contrast to the attention given to Fe on variously prepared GaAs substrates, the magnetism of Fe on vicinal GaAs substrates has received scant attention. This in spite of the fact that films grown on vicinal substrates present a number of advantages and opportunities. For example, they are known to exhibit enhanced structural homogeneity, surface diffusion tends to follow well mapped patterns (the quasi-periodicity has been exploited to produce quantum wires) and there is an additional degree of control of the film growth beyond those associated with temperature and substrate surface composition[7].

In a preliminary combined spin-polarized secondary electron spectroscopy, photoelectron spectroscopy and LEED study (carried out on the SRS, Daresbury Laboratory) of the remanent magnetic properties of Fe on singular and vicinal (3° offset) GaAs we have shown both that the various magnetic phases formed are dependant upon the Ga to As surface composition of the substrate and that they evolve in characteristic (but not well understood) ways with Fe overlayer thickness[8]. A remarkable feature in this system, which illustrates the importance of the Fe overlayer/substrate interaction, is the magnetic anisotropy; the easy axis of the Fe films on Ga-terminated substrates is perpendicular to that for As-terminated substrates[9,10].

These measurements were followed up with combined spin-resolved photoemission and magnetic linear dichroism experiments on Fe deposited on vicinal (offcut by 3º and 6º) or singular GaAs substrates on Beamline 7 at the ALS. The GaAs(100) substrates were available for film deposition at room temperature after substrate decapping *in-situ* (by thermal annealing), at the ALS. By mounting both singular and vicinal GaAs substrates on the same sample tile the same growth conditions applied for both films facilitating direct comparison. The surface quality was monitored using LEED. The following data were obtained, (i) high resolution spin-integrated valence bands, (ii) the spin-resolved

valence bands and their energy dispersion, (iii) the film thickness dependence of the spin-resolved valence bands, (iv) magnetic linear dichroism data on the Fe3p and Fe2p core levels at a variety of photon energies.

The experiments, have produced a considerable number of interesting results. A significant difference in the spin-resolved valence bands between *ca.*20 Å thick Fe films on singular and vicinal (3º) GaAs were observed. As the terrace width is *ca.*55 Å the spectral differences are not due to step-localized feature. Other interesting results include the following. At low Fe thicknesses, samples were observed to be non-magnetic at room temperature but upon cooling became magnetic at a temperature that is highly dependant upon the Fe film thickness. This is thought to be the first direct observation of super-paramagnetism in the island growth phase proposed for Fe thickness of approximately 10Å. Such behaviour had been previously predicted by some authors but disputed by others. Also, Fe deposited on singular substrates reveals a larger energy dispersion of the spin-resolved valence bands than Fe on vicinal substrates. Only marginal differences can be seen between the spin-resolved valence bands of Fe deposited on 3º stepped GaAs substrates and Fe deposited on 6º stepped GaAs substrates. In contrast, the linear magnetic dichroism results obtained for these samples are very similar.

More recent experiments at ALS have enabled us to obtain many more interesting results including Fermi surface and band mapping data of the valence band structure of Fe overlayers as a function of thickness for both singular and vicinal substrates. This run also enabled us to obtain much more extensive temperature dependent data on samples with thicknesses close to, and either side of, the super-paramagnetic limit to further investigate this phenomenon. The effect of modifying the interface between the Fe and GaAs was also studied. Thin (sub-monolayer) quantities of materials such as Ce and O were deposited at the interface and this has been shown to result in a significant impact on the overall work function, magnetic behaviour, diffusion rates and band structure of the samples. Analysis of these data is still ongoing.

References:

[1] Malajovich I., Berry J.J., Samarth N. and Awschalom D.D., Nature 411, 770 (2001)

[2] Ohno Y., Young D.K., Beschoten B., Matsukura F., Ohno H. and Awschalom D.D., Nature 402, 790 (1999)

[3] Filip A.T., Hoving B.H., Jedema F.J., van Wees B.J., Dutta B. and Borghs S., Phys. Rev. B 62, 9996 (2000)

[4] Hammar P.R., Bennett B.R., Yang M.Y. and Johnson M., Phys. Rev. Lett. 83, 203 (1999)

[5] Kikkawa J.M. and Awschalom D.D., Nature 397, 139 (1999)

[6] Kikkawa J.M. and Awschalom D.D., Phys. Rev. Lett. 80, 4313 (1998)

[7] Joyce B. A., Neave J. H., Zhang J., Vvedensky D. D., Clarke S., Hugill K.J., Shithara T. and Myers-Beaghton A.K., Semicond. Sci. Technol., **5** 1147 (1990). Kawamura T., Maruta J. and Ishii A., J. Appl. Phys., **39** (7B) 4376 (2000). Gaines J.M., Petroff P.M., Kroemer H., Simes R.J., Geels R.S. and English J.H., J. Vac. Sci. Technol., **B6** 1373 (1998).

[8] Zhang T., Spangenberg M., Greig D., Takahashi N., Shen T-H., Matthew J.A.D., Cornelius S. M., Rendall M. and Seddon, E.A., Appl. Phys. Letters, **78** 961 (2001)

[9] Kneedler E. M., Jonker B. T., Thibado P. M., Wagner R. J., Shanabrook B. V., and Whitman L., J. Phys. Rev. B, **56** 8163 (1997).

[10] Gester M., Daboo C., Hicken R. J., Gray S. J., Ercole A., and Bland J. A. C., J. Appl. Physics **80** 347 (1996).